The Beam Cursor: A Pen-based Technique for Enhancing Target Acquisition

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In this paper we introduce a novel interaction technique that improves target acquisition in pen-based interfaces. This technique is called Beam Cursor. The Beam Cursor exploits the *sliding* motion and dynamically updates the effective width of targets on screen according to the original location of the pen-tip, such that even if the pen-tip lands in the vicinity of a target the target can easily be selected. We also provide reports on two controlled experiments which were performed to evaluate the Beam Cursor in both 1D (dimension) and 2D target selection tasks on the pen-based interface. The experimental results indicate that the Beam Cursor is modeled on and predicted by Fitts' law and that it is governed by the effective width of the targets. Results also show that the Beam Cursor significantly outperforms the Point Cursor and the Bubble Cursor [Grossman and Balakrishnan 2005]**.**

Keywords: Slide Touch, Beam Cursor, Fitts' law, graphical user interface, target selection.

1 Introduction

Ubiquitous computing inspires technique development of pen-based interactions. Currently, pen-based devices have been used widely, such as PDAs, Tablet PCs and whiteboards. In such situation more and more researchers have pay attention to these study issues. Target selection is a very fundamental computing task. As the different display sizes and styles of user interfaces emerges the selection task becomes more complex, so that studies aimed at improving target selection have become essential and very significant. Hence, many researchers have proposed various techniques that attempt to enhance target selection. However, most of these new techniques have been designed for mice. But the selection of targets using a stylus pen has some specific and unique characteristics which do not apply to the mouse interface. Two examples are, the lifting and pressing of the pen-tip and the sliding of the pen tip across the screen surface. Obviously, selection techniques that are suitable for mouse interfaces do not necessarily suit the special characteristics of stylus pens. Conversely, it seems equally obvious that the optimal performances of each of these significantly different devices will be achieved by significantly different kinds of operations, techniques and graphic elements.

Therefore, we present the Beam Cursor, a new selection technique which is based on the Slide Touch strategy [Ren and Moriya 2000], which is tailored for pen-based interfaces. Ren and Moriya [2000] studied several selection task techniques for pen-based interfaces and drew the conclusion that the Slide Touch strategy (Figure 1a) outperformed the other five selecting task techniques that they tested. In this technique, the pen-tip initially lands outside a target then slides towards the target; when the pen-tip touches the target the target is selected. The Beam Cursor enhances this technique by adding a virtual target size to the normal physical target size. The virtual target size feature means that the Beam Cursor dynamically updates the effective region of targets. When the pen-tip touches the screen surface, the Beam Cursor uses the initial contact point as a reference point, and divides the total space in which all targets reside into regions, so that there is just one target inside each region. When the pen-tip slides towards a target and enters the effective region of the target, the target is pre-selected and is contained by the beam (transparent red shading) which is "emitted" from the cursor. When the pen-tip is taken off the screen surface the target is selected. (Figure 1b)

In the following sections, we will review previously published research reports dealing with pointing facilitation. We will then discuss the design and implementation of the Beam Cursor, evaluate the performance of the Beam Cursor in two experiments, and show that the Beam Cursor's performance can be

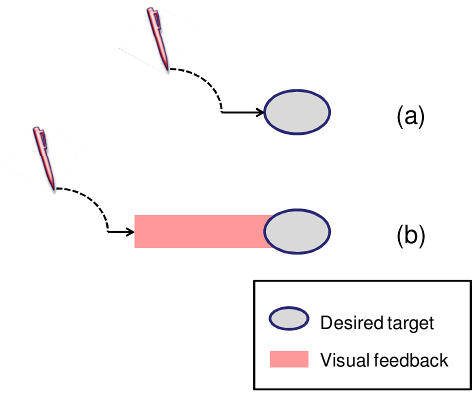

Figure 1. (a) The Slide Touch strategy: the pen-tip initially lands outside the target then slides towards the target; when the pen-tip touches the target the target is selected. (b) The Beam Cursor: the pen-tip lands on the screen surface then slides towards the desired target and the target is pre-selected and contained within a "beam" (shaded area) which is emitted from the cursor in the direction of the target; when the pen-tip is lifted the target is selected. The dot line means the pen movement trace above a screen surface while the solid line means the pen sliding trace on the screen surface.

modelled by Fitts' law. We will conclude by discussing some implications for user interface design and also future work.

2 Related work

2.1 Expanding Target or Reducing Distance

Fitts'law [Fitts 1954] is commonly used to predict the time it takes to move a mouse pointer from one location to another.

$$MT = a + b\log_2\left(\frac{A}{W}+1\right) \qquad (1)$$

According to Fitts'law, the cursor movement time (*MT*) increases linearly with the Index of Difficulty (*ID*), which relies on the logarithm of the distance moved (the amplitude, *A*) and the width of the target (*W*). The two constants, *a* and *b*, are determined empirically and depend on cognition, motor preparation time and on hand-eye coordination. With respect to Fitts' law, there are two simple ways to reduce the difficulty of a pointing task: increasing the target width or reducing the amplitude.

Regarding the virtual target size, a target has an effective width which can be defined as the effective area of a target which has been expanded beyond it's physical graphical width. One approach to improving target acquisition is to increase the target's width. McGuffin & Balakrishnan [2002] closely examined the degree to which Fitts' Law modeled actions aimed at selecting expanding targets in one-dimensional tasks. They found that Fitts' Law accurately models the performance of such actions, and that movement time is primarily governed by the final expanded size of the target. This result held even when the targets began expanding after most of the movement towards the target (90%) was complete. McGuffin & Balakrishnan's [2002] study examined selection of a single object with no surrounding objects, so the influence of distraction due to movement of neighboring objects was not examined.

Kabbash & Buxton [1995] investigated the use of area cursors. The basic idea is that an area cursor has a larger active region or hotspot for target selection, rather than a single pixel hotspot as in standard cursors. Kabbash & Buxton [1995] showed that by setting *W* to be the width of the area cursor, selection of a single pixel target could be accurately modeled using Fitts' law. Thus, very small targets would have a much lower index of difficulty when selected by an area cursor. However, a problem of ambiguity arises when the desktop environment is densely populated with targets, as multiple targets could fall inside the area cursor at one time. Grossman & Balakrishnan [2005] proposed the Bubble Cursor which improves upon area cursors by dynamically resizing its activation area depending on the proximity of surrounding targets, so that only one target is selectable at any time. The evaluation results prove that the Bubble Cursor significantly reduces target acquisition times in both simple and complex multi-target environments.

A way to reduce *A* (the amplitude) is to bring the target closer to the cursor. Bezerianos & Balakrishnan [2005] developed the vacuum technique which can bring distance targets closer to the widget's center in the form of proxies that can be manipulated in lieu of the original. This technique is suitable for large screens. An alternative is to jump the cursor to the target. Guiard et al. [2004] proposed a selection technique called Object Pointing. In this technique the cursor never visits the empty regions of graphical space. It jumps from one selectable target to another. Object Pointing was found to be considerably faster than regular pointing in a 1D reciprocal pointing task. However in a 2D environment, it was shown that the degree to which object pointing outperformed regular pointing was dependent upon the density of the targets.

There have been a number of efforts to facilitate pointing by dynamically adjusting the control display (CD) gain. Worden et al. [1997] implemented 'Sticky Icons' by decreasing the mouse control-display gain when the cursor enters the icon. Control-display gain determines the mapping between physical mouse movement and resultant cursor movement. In this way, the user must move the mouse further to escape the boundary of the icon, effectively making the icon larger without using extra screen space. Worden et al.'s evaluation showed Sticky Icons to be efficient for selecting small targets. In a technique called *semantic pointing*, Blanch et al. [2004] showed that performance could be predicted using Fitts' Law, based on the resulting larger W and smaller A in motor space. Once again, however, problems arise when multiple targets are presented as the intervening targets will slow the cursor down as it travels to its destination target.

2.2 Other Selection Techniques

Beside target selection techniques described above, there are still techniques that based on specific operation manners. Ren & Moriya [2000] compared pen-based selection techniques and their characteristics, and proved that the proposed Slide Touch strategy is the best of the six techniques. Slide Touch is where the target is selected at the moment the pen-tip touches the target for the first time after landing on the screen surface. The experimental results show that it is particularly useful in situations where the target is isolated or where targets are arranged sparsely. The RadarView technique uses a reduced representation (a map) of the entire environment. the Radar map proportionally reduces both the size of objects and space between them and allows continuous positioning of the object within the map.Guan et al. [2004] presented the *Zoom Selector* which pre-selects, enlarges and relocates the targets covered by a transparent round circle into a large pie sector to enhance the target's acquisition. The evaluation results indicate that the *Zoom Selector* outperforms the normal click method when used for small targets. It is suitable for small target acquisition or situations where targets are arranged densely.

3 Beam Cursor Design and Implementation

The Beam Cursor is an interaction technique that enables quick access to targets on areas of a pen-based display. The Beam Cursor employs the *sliding* action of the stylus pen and dynamically updates the effective width of the target according to the contact point of the pen-tip and the layout of the surrounding targets, thus enhancing the target's acquisition. When the pen-tip lands on the screen and slides towards a target, the target is included in a "beam" which is "emitted" from the

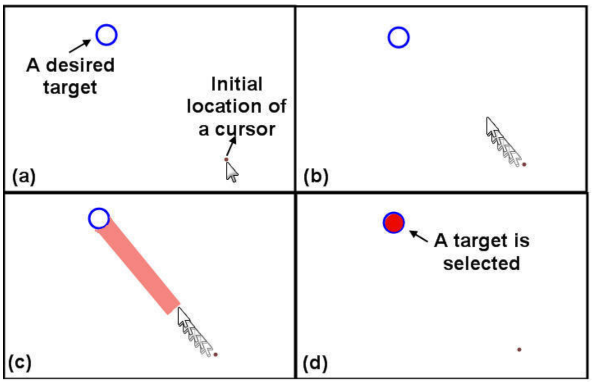

Figure 2. (a) A pen-tip lands on screen surfaces and its initial location is recorded; (b) the pen-tip slides to the desired target; (c) when the cursor enters the effective region of a target the target is contained by a transparent red beam emitting from the cursor; (d) the pen-tip lifts from the screen surface then the target is selected.

cursor. This means that the target is pre-selected as the stylus approaches and it is selected when the pen-tip is lifted from the screen surface (see figure 2).
In designing the Beam Cursor, we explicitly sought to address Slide Touch, which is the inspiration of the Beam Cursor.

Slide Touch [Ren & Moriya 2000] is the technique whereby the target is selected at the moment the pen-tip touches the target for the first time after landing on the screen surface. It is a very useful selection technique for pen-based interfaces. However, the technique requires the pen-tip to touch the target which is to be selected before selection can be affected. The Beam Cursor combines the virtual target concept and the Slide Touch strategy to enhance target acquisition. That is, every target is allocated an effective width which is bigger than its physical width. The following section discusses how the effective width is allocated to each target.

Regarding virtual target size, every target has an effective width based on its physical width in motor space. During the actual process of target selection, the user can first determine the target that he/she will select. Aiming at the desired target, the Beam Cursor allocates the effective regions of all the targets to enable the desired target to occupy a much bigger effective region. A simple algorithm is used to continuously update the effective regions of targets (see figure 3).

● When the pen-tip lands on the screen surface, the contact point is recorded as the reference point.

● Taking that point as the center point, the Beam Cursor divides the total space into *n*[1] equal sectors (If the screen is divided into too many sections the error rate is

[1] There is a closest target to the pen-tip in the screen, which can be determined by pure Voronoi dagram principle. However, in fact, in each direction area of the screen a possible closest target to the pen-tip exists. To find it the Beam Cursor first divides the whole screen into some sections.

quite high. The tradeoff of speed and accuracy should be considered. Therefore, based on an informal test *n* is set at 15). The targets in the same sector constitute a group.

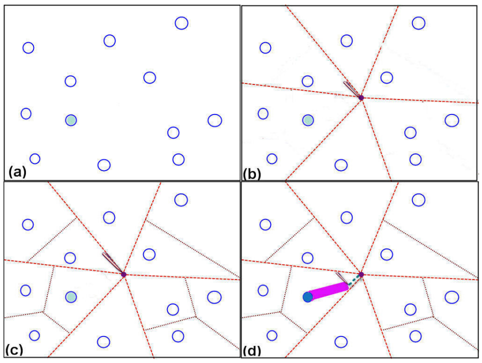

Figure 3. (a) There are many targets in the screen, where the solid blue target is the goal target; (b) When pen lands on screen surface, the initial point is recorded as reference point, which is used as a center point to divide the screen into n sectors (to clear demonstrate the principle, n is set at 6 in the figure 3. At fact, the Beam Cursor sets n at 15.). The targets in the same sector constitute a group. (c) Targets in the same group are allocated effective regions according to the Voronoi diagram principle. (d) When a cursor slides into a certain sector the target that is closest to it is pre-selected. Note that all the dot-lines are unseen in the real interfaces.

● Targets in the same group are allocated effective regions according to the Voronoi diagram principle. So when a cursor slides into a certain sector the target that is closest to it is pre-selected.

With respect to all possible arrangements for the targets, if there is only one target in one sector the whole sector is the effective region of the target; if there are multiple targets in one sector the targets in the same group are allocated effective regions according to the Voronoi diagram principle. If the target is one the border of two sectors, in this case the target belongs to both sectors.

Based on this algorithm the pen-tip can land on any possible position in the vicinity of the target to enable it to have a much bigger effective region. The pen-tip then to travel a very short distance to enter the effective region of the desired target. Even if the pen-tip lands on a position imprecisely, a slight movement towards the target affects pre-selection of the desired target. When the cursor enters the effective region of a target the target is contained by a transparent red beam emitting from the cursor. This acts as a reinforcing visual cue to the user, showing that the desired target is indeed pre-selected by the cursor, thus reducing the cognitive load of the user and eliminating any uncertainty about which target will be selected when the pen is removed.

With respect to "abort" of a selection task that the Bubble Cursor also faces, the method the Beam Cursor employed is to press an additional button (key) using non-preferred hand [Li et al. 2005] to do it, which, in essence, is the mode-switch between selection and non-selection states.

4. Experiment 1

The Beam Cursor not only enlarges the effective width of the target but also dynamically updates it, based on the pen-tip's initial landing point on the screen surface. From previous work on expanding targets [McGuffin and Balakrishnan 2002, Zhai et al. 2003], it was found that users were able to take advantage of the larger expanded target width even when expansion occurred after 90% of the distance to the target had already been traveled. It was also shown that overall performance could be modeled accurately by Fitts' law by setting *W* to the expanded target width. So we would expect that Fitts' law would hold in situations where the effective width of targets dynamically changes when selecting targets. However, the Beam Cursor has a few specific properties that make it difficult to directly apply Fitts' law to model it.

1. Once the pen-tip lands on the screen surface, the effective width of the target changes.
2. Before capturing a target, the Beam Cursor should be slid towards the target for a very short distance.

It is important to empirically determine if Fitts' law holds for Beam Cursors. This is the first goal of Experiment 1.

Even if the Fitts' law is shown to model the Beam Cursor performance accurately, this does not necessarily mean that the Beam Cursor provides a significant advantage over Point Cursors. Furthermore, the Beam Cursor enhances target acquisition by enlarging the effective width of targets. And, based on the principle of allocating the effective region to the intended target, the Beam Cursor expands the effective width of the target the user wants to select while shrinking other targets. So we wondered whether the performance is governed by the effective width rather than the actual width of the target. In other words, selecting a target with an actual width *W* and an effective width *EW* with a Beam Cursor should be equivalent to selecting a target with an actual width of *EW* with a regular Point Cursor. Thus, the second goal of Experiment 1 is to determine whether performance is governed by and makes maximum use of the effective width.

To answer these questions in a systematic manner, we begin by studying the Beam Cursor performance in the simplest possible pointing task: 1D target acquisition. We compare the Beam Cursor with the Point Cursor in Experiment 1.

4.1 Apparatus

The hardware used in Experiment 1 was the Fujitsu Tablet PC running Microsoft Windows XP. It weighed 1.48kg, and was 210.432 mm (W) x 157.824mm (H). The spatial resolution of the screen was 0.2055 mm/pixel. The software for the experiment was developed using Sun Microsystems Java.

4.2 Participants

Eighteen subjects (three females and fifteen males) who had all had previous experience with computers were tested for the experiment. The average age was 22.5. All subjects had normal or "corrected to normal" vision with no color blindness, were right handed, and used the pen in the right hand.

4.3 Procedure and Design

The task was a reciprocal 1D pointing task in which subjects were required to select two fixed targets back and forth. The targets were arranged as solid circles, keeping a distance between them along the horizontal axis. The target to be selected was colored green, and the other target was red. In reality, if there were only two targets on the screen, the effective width of targets in a Beam Cursor interface would be very big. The subject would only have to move the stylus pen a very short distance to select the target. Thus, to simulate the realistic target acquisition scenario some distracter targets were placed around both goal targets such that their effective widths (*EW*) were controlled. Distracters were rendered as

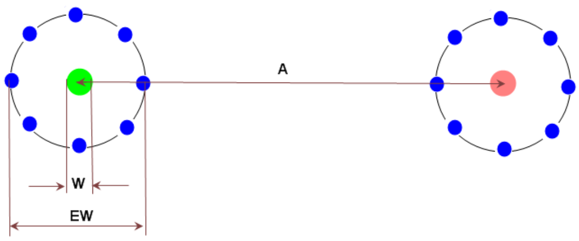

Figure 4. The setup of the 1D reciprocal pointing experiment. The green circle is the target to be selected. The red circle is the next goal target. Blue circles are placed to control the *EW/W* ratio. Note: EW is an approximate value, which is gotten based on the effective width allocation principle of Beam Cursor.

blue solid circles (see Figure 4). Subjects were instructed to select between the two targets alternately. They were told to emphasize both accuracy and speed. When the subject correctly selected the target he/she would hear a beep sound and the targets would swap colors, which was an indication that the subject had to now move towards and select the other target which was now green.

The design of the experiment was as follows: crossed Cursor Technique (*CT*) x Amplitude (*A*) x Width (*W*) x Effective Width (*EW*). A full crossed design resulted in 54 combinations of *CT* (Point Cursor, Beam Cursor), A (288, 576, 864 pixels), *W* (12, 24, 36 pixels), *EW* (48, 96, 144 pixels). Each subject had a total of 27 combinations (=3 Amplitudes x 3 target widths x 3 target effective widths) appearing in random order (partial counterbalancing) for each technique. Each combination consisted of 5 selection attempts (i.e., four reciprocal movements between the two targets). At the start of the experiment, for each cursor technique, subjects were given a warm-up block of attempts to familiarize them with the task and conditions. Each subject performed the experiment in one session lasting approximately thirty minutes, depending on each subject's proficiency in selecting the targets. The session was broken up according to cursor technique. Whenever the subject felt tired he/she was allowed to take a rest.

4.4 Results

An ANOVA (analysis of variance) with repeated measures was used to analyze performance in terms of movement time, error rate and subjective preference. Post hoc analysis was performed with Tukey's honestly significant difference (HSD) test.

4.4.1 Selection Time

The analysis showed that there was significant difference between the Point Cursor and the Beam Cursor in selection time, $F(1,34)=21.43$, $p<0.001$. The overall mean selection times were 958 milliseconds for the Point Cursor and 718 milliseconds for the Beam Cursor. A repeated measures analysis of variance also showed a significant main effect for *W*, $F(2,105)=23.51$, $p<0.01$; *EW*, $F(2,105)=56.25$, $p<0.01$; and *A*, $F(2,105)=78.54$, $p<0.01$. For each of combinations of *W* and *EW* the analysis showed that Beam Cursor was significant faster than the Point Cutsor, all at $p<.05$ level. As Figure 5 illustrates, performance of the Beam Cursor is dependent on *EW* rather than *W* whereas performance of the Point Cursor depends on *W*.

Figure 6 plots the movement time as a function of the index of difficulty (*ID*). For the Point Cursor, we define *ID* as $log_2(A/W + 1)$, while for the Beam Cursor, $log_2(A/EW + 1)$. Linear regression analysis showed that the Point Cursor fits the Fitts' law equation with r^2 values 0.9599 and the Beam Cursor fits the Fitts' law equation with r^2 values 0.8727. Here the r^2 value is a little low, which is due to the fact that the effective width of targets is an approximation based on the allocation principle of the effective width in Experiment 1. This means that selection using the Beam Cursor can not only be modeled using Fitts' law, but selection is just as fast as if the target had an actual width of *EW* and a Point Cursor were being used.

4.4.2 Error Score

The analysis of mean error score shows that there was no significant difference between the Point Cursor and the Beam Cursor. Overall error rates were 2.78% for the Point Cursor and 3.24% for the Beam Cursor, all well within the typical < 4% range seen in target acquisition studies.

5 Experiment 2

Experiment 1 determined that the Fitts' law can model the Beam Cursor and predict the selection time in 1D reciprocal pointing tasks. The experimental results show that Fitts' law can model and predict the Beam Cursor. It also shows that selection performance is governed by the effective width of targets rather than their physical width. In Experiment 1, the Beam Cursor significantly reduced selection time, which further indicates that increasing the effective width of targets does enhance target acquisition.

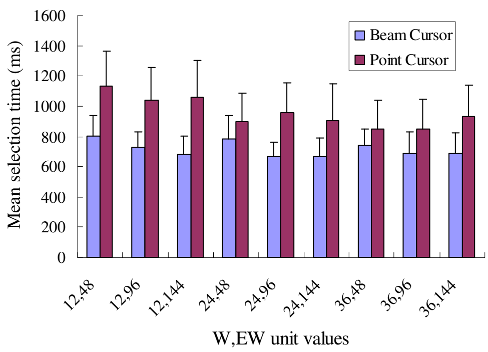

Figure 5. The mean selection time by *W, EW* values for both cursors

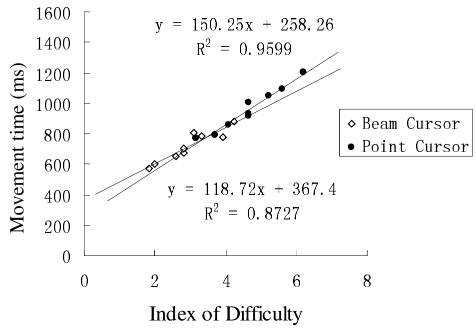

Figure 6. Line regression of target distance against movement time.

However, the experiment on 1D targets is an easy and abstract scenario contrasting to actual user interfaces. So we wondered whether the Beam Cursor delivers the same advantages with complex 2D situations. In the second experiment, we explore the Beam Cursor's performance in a more realistic environment with multiple 2D targets with various target widths and layout densities.

If the space surrounding targets is bigger, the effective width of targets will be bigger. In Experiment 2 we will probe this further. And we include the Bubble Cursor [Grossman & Balakrishnan 2005] which is discussed in the related work section. This technique is perhaps more promising than other existing techniques for improving target acquisition. In the previous work on the Bubble Cursor, it is found that, taking mice as the input device, the Bubble Cursor significantly decreases selection time. So we wondered if the Bubble Cursor offers the same advantage when a stylus pen is the input device? In other words, we wanted to know whether the technique that is suitable for mice is also as suitable for stylus pens. Since the Beam Cursor is a direct extension of the Slide Touch strategy, there is no reason to expect it to perform *worse* than Slide Touch. This was confirmed in pilot studies, and as such we did not include Slide Touch in our experimental comparison.

5.1 Apparatus

The apparatus was the same as in Experiment 1.

5.2 Participants

Eighteen subjects (three females and fifteen males) who had all had previous experience in computers were tested for the experiment. The average age was 22.7 years. Twelve of them were test subjects in Experiment 1. All subjects had normal or “corrected to normal” vision with no color blindness, all were right handed, and all used the pen in the right hand.

5.3 Procedure and Design

This experiment tested 2 dimensional and multiple target display arrangements. The selection task was serial in contrast to the simple reciprocating movement required for Experiment 1. The target to be selected was green and the others were pale red.
In this experiment, subjects were required to select the green target which appeared randomly among a number of pale red targets on the display. When a selection performance was finished, that green target would change to red and another target would become green indicating that it is the new target. This design required the user to jump in any direction on the screen, not just horizontally as in Experiment 1.

Subjects needed to finish multiple sets of selection tasks. For each set of selection tasks, the number and the width of targets on the screen were different. When the experiment began, the subject saw a green target. The time for the task was recorded from the moment the first green target was selected. Each interval for the two selection actions was recorded. This allowed us to analyze the time of each selection and the total time of all the selection tasks. A successful selection resulted in a beep sound. If no beep sound was heard, it meant that an error had occurred. The feedback we provided was the same as in Experiment 1. When a target was preselected it would be contained by a transparent red beam emitted from the cursor.

The design of the experiment was as follows: crossed Cursor Technique (*CT*) x Width (*W*) x Density (*D*). A full crossed design resulted in 27 combinations of *CT* (Beam, Point, Bubble), *W*(12, 24, 36 pixels), Density (6, 12, 30). For each of the three techniques, 9 combinations (=3 target widths x 3 target densities) appeared in a random order. Each subject had a total of 144 attempts (3 widths x (6 + 12 + 30) densities). At the start of the experiment, subjects were given a warm-up session for each cursor technique to familiarize them with the task and the conditions. Each subject performed the experiment in approximately forty minutes, depending on individual proficiency. The experiment was broken up according to cursor technique. Whenever the subject felt tired he/she was allowed to take a rest.

5.4 Results

5.4.1 Selection Time

A repeated measures analysis of variance showed that there was a significant interaction between the three cursor techniques in selection time, $F(2,51)=10.2$, $p<0.001$. The post hoc Tukey (HDS) test showed that the Beam Cursor was faster than both the Point Cursor and the Bubble Cursor $F(1,34)=23.5$, $F(1,34)=5.4$ ($p<0.05$). The Bubble Cursor was significantly faster than the Point Cursor in selection time. The overall mean selection times were 1196 milliseconds for the Beam Cursor, 1483 milliseconds for the Point Cursor and 1353 milliseconds for the Bubble Cursor (see figure 7). The results clearly show that the Beam Cursor can improve target acquisition in complex 2D experimental circumstances. On a pen-based interface and using a stylus pen, the Beam Cursor significantly surpasses

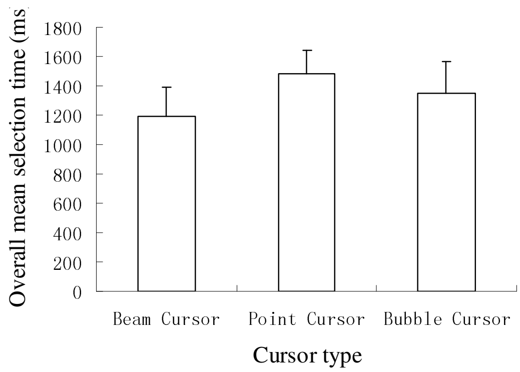

Figure 7. The overall mean selection time for the three cursor techniques

the Bubble Cursor [Grossman & Balakrishnan 2005]. One reason is that the Beam Cursor can endow a much bigger effective region to the desired target than the Bubble Cursor. The other reason is that, in the experimental circumstances of a pen-based interface, the constant lifting of the pen-tip, limits the advantage of the Bubble Cursor. The results also indicate that the selection targets using a stylus pen has its own specific characteristics and that selection techniques that suit mice are not necessarily suitable for stylus pens.

Target width: A significant difference in selection time was observed between the three cursor techniques for each target width, 12, 24 and 36 pixels, $F(2,51)=14.64$, $F(2,51)=9.28$ and $F(2,51)=7.84$, $p<0.001$. This means that significant differences in selection times remained when the target width was varied. As seen in Figure 8, with the target width increasing the selection time did not significantly decrease for the Beam Cursor. This is due to the fact that the Beam Cursor is governed by the effective width of targets, not the physical width of the target.

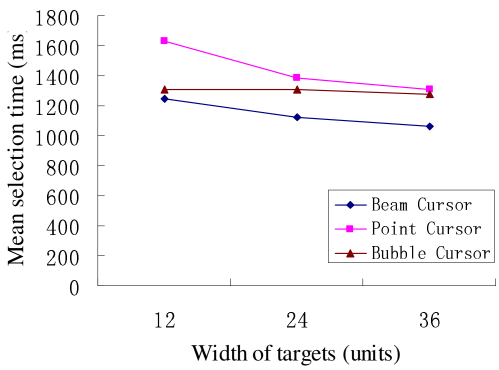

Figure 8. The mean selection time for targets of different target widths.

Target density: A significant difference in selection time was observed between the three cursor techniques for each target density, 6, 12 and 30, $F(2,51)=13.05$, $F(2,51)=7.23$ and $F(2,51)=10.32$, $p<0.001$. This means that significant differences in selection times remained when the target density was varied. As seen in Figure 9, when the target density was small the difference between the Beam Cursor and the Point Cursor became more significant. This was due to the fact that, when the target density was small, the void space among the targets became wider and the effective width of targets increased. So, for the situation in which targets are placed tightly together, the Beam Cursor probably has a little advantage in selection time.

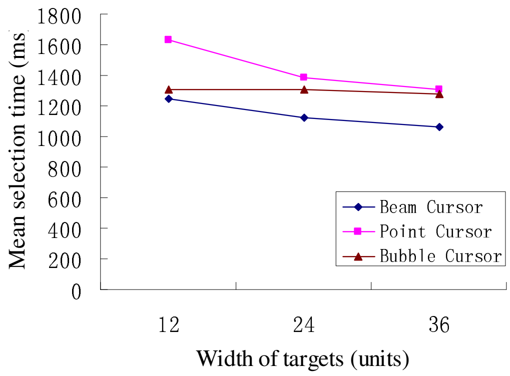

Figure 9. The mean selection time for targets in layouts with different target densities.

5.4.2 Error Score

The analysis of the mean error score showed that there was no significant difference between the Beam Cursor, the Point Cursor and the Bubble Cursor. Overall error rates were 2.98% for the Beam Cursor, 3.12% for the Point Cursor and 2.45% for the Bubble Cursor, all well within the typical < 4% range seen in target acquisition studies.

5.4.3 Subjective Preference

There was a significant difference between the Beam Cursor, the Point Cursor and the Bubble Cursor in subjective preference, $F(2,51)=18.28$, $p<0.001$. The post hoc Tukey (HSD) test showed that the Beam Cursor was better than both the Bubble Cursor and the Point Cursor, $p<0.05$. The Bubble Cursor was better than the Point Cursor, $p<0.01$.

6 Discussion and Conclusion

The article proposes an interactive technique called Beam Cursor, which enables the quick selection of targets on pen-based interfaces. The Beam Cursor employs the *sliding* motion and dynamically updates the effective width of targets according to the initial contact point of the pen-tip and the layout of the surrounding targets. The aim is to enhance target acquisition. We then described the methods and results of Experiment 1 and Experiment 2 respectively.

Experiment 1 verified that the Beam Cursor can be modeled and predicted by Fitts' law using the one dimension reciprocal pointing task. We compared the Beam Cursor with the Point Cursor. The evaluation results show that Fitts' law can model the Beam Cursor and predict the selection time. Selection performance is governed mainly by the effective width of targets, not by the physical width of targets. The Beam Cursor outperforms the Point Cursor for the different *E/EW* ratio.

Experiment 1 is a simple abstract experimental circumstance. Experiment 2 further evaluates the effectiveness of the Beam Cursor on target acquisition. In the second experiment we introduced a current promising selection technique, the Bubble Cursor. We evaluate the three selection techniques under the condition of different target densities and different target widths. The experimental results indicate that the Beam Cursor is better than both the Point Cursor and the Bubble Cursor. There is no significant difference between the Point Cursor and the Bubble Cursor.

Pen devices have specific interactive characteristics: e.g. the lifting and pressing of the pen-tip and the ability to slide the pen-tip on the screen surface. When contrasted with the normal click of a mouse, the unsteadiness of the pen tip can make the press and click action inaccurate. This unsteadiness makes it difficult for users to hit a precise point on a target. According to our observations, it is very common for the pen tip to make contact within a larger range near but outside the target because of the touch screen's slipperiness and the pen tip's vibrations. Therefore, allowing some tolerance in the initial location of the pen-tip and providing a simple means of adjustment via a hand movement which approaches the target would appear to greatly decrease the effect of an imprecise touchdown as well as decreasing the cognitive load of the user. That is why the Beam Cursor exploits the *sliding* motion.

Virtual targets means that every target has an effective width based on its physical width in its relation to the motor space surrounding it. Actually, selection techniques, such as the area cursor [Kabbash & Buxton 1995] and the Bubble Cursor [Grossman & Balakrishnan 2005], expand the target width to enhance selection performance. In other words these techniques make full use of the void space around the targets in motor space. The Bubble Cursor employs the Voronoi diagram to increase target size in motor space to the maximum. However, the Beam Cursor allocates the effective region to targets giving priority to the desired target. The goal of this allocation principle is to endow a much bigger effective region to the desired target.

We also found the Beam Cursor to be better than the Bubble Cursor, one of the more promising selection techniques in the literature. However, we must be careful before drawing too many conclusions about the relatively poor performance of the Bubble Cursor in our experiment. The Bubble Cursor is able to enhance selection performance where mice are used as input devices. We compared the Beam Cursor with the Bubble Cursor in the pen-based interface, and found that this environment

limits the advantage of the Bubble Cursor to some extent. This indicates that selection techniques designed for mice are probably not suitable for stylus pens.
Another characteristic of the Beam Cursor is that it enhances target acquisition without changing the position and size of targets, unlike some other selection techniques [Guan et al. 2004, Zhai et al. 2003], The Beam Cursor dynamically updates the effective width of targets without altering the arrangement of items on the screen.

The effective width determines the selection performance of the Beam Cursor and the void space around targets governs their effective width. So even if a target is very small but its surrounding void space is wide, its effective width is still big and its Index of Difficulty (ID) with regard to selection is quite small. Obviously, the Beam Cursor does not yield any benefit for target selection on a screen where the targets are laid side to side because there is almost no void space among the targets and the effective width of targets is almost equal to their physical width.

The positive results from our experiments suggest that the Beam Cursor could be a beneficial addition to user interfaces. We can develop a plug-in to incorporate the Beam Cursor into user interfaces. This would be very appropriate to exploit "selection" mode. We can design an appropriate command to allow switching between the Beam Cursor and the Point Cursor. For example, we can set a command button on the taskbar; when the user wants to select targets by Beam Cursor, he/she would just click the command button to activate the Beam Cursor. Or it may be activated by setting this command as an item in the pop-up menu which is also convenient for the user.

References

Accot, J., Zhai, S. [1997], Beyond Fitts' law: models for trajectory-based HCI tasks. *In proceeding of the ACM Conference on Human Factors in Computing Systems (CHI'97)*, pp. 295-302.

Aurenhammer, F. and Klein, R. [2000], *Voronoi Diagrams. Chapter 5*, in *Handbook of computational geometry*, J. Sack and J. Urrutia, Editors. North-Holland: Amsterdam, Netherlands, pp. 201-290.

Bezerianos, A., and Balakrishnan, R. [2005], The Vacuum: Facilitating the Manipulation of Distant Objects. *In proceeding of the ACM Conference on Human Factors in Computing Systems (CHI'05)*, pp. 361– 370.

Baudisch, P., Cutrell, E., Robbins, D., Czerwinski, M., Tandler, P., Bederson, B., and Zierlinger, A. [2003]. Drag-and-pop and drag-and-pick: Techniques for accessing remote screen content on touch- and penoperated systems. *Proceedings of Interact (2003)*, pp. 57-64.

Blanch, R., Guiard, Y., and Beaudouin-Lafon, M. [2004], Semantic pointing: improving target acquisition with control-display ratio adaptation. *In proceeding of the ACM Conference on Human Factors in Computing Systems (CHI'04)*, pp. 519-525.

Cockburn, A. and Firth, A. [2003]. Improving the acquisition of small targets, *British HCI Conference*, pp. 181-196.

Fitts, P.M. [1954], The information capacity of the human motor system in controlling the amplitude of movement, *Journal of Experimental Psychology*, pp. 381-391.

Grossman, T., and Balakrishnan, R. [2005], The Bubble Cursor: Enhancing Target Acquisition by Dynamic Resizing of the Cursor's Activation Area, *In proceeding of the ACM Conference on Human Factors in Computing Systems (CHI'05)*, pp. 266– 271.

Guan, Z., Ren, X., Li, Y., and Dai, G. [2004], Zoom Selector: A Pen-based Interaction Technique for Small Target Selection, *IPSJ Journal*, pp 2087-2097.

Guiard, Y., Blanch, R., and Beaudouin-Lafon, M. [2004], Object pointing: a complement to bitmap pointing in GUIs, *Graphics Interface*, pp. 9-16.

Kabbash, P. and Buxton, W. [1995], The "Prince" technique: Fitts' law and selection using area cursors, *In proceeding of the ACM Conference on Human Factors in Computing Systems (CHI'95)*, pp. 273-279.

Keyson, D. [1997], Dynamic cursor gain and tactual feedback in the capture of cursor movements, *Ergonomics*, Vol.12, pp. 1287-1298.

Li, Y., Hinckley, K., Guan, Z., and Landay, J.A. [2005], Experimental analysis of mode switching techniques in pen-based user interfaces. *In proceeding of the ACM Conference on Human Factors in Computing Systems (CHI'05)*, pp. 461-470.

MacKenzie, I., and Riddersma, S. [1994], Effects of Output Display and Control-Display Gain on Human Performance in Interactive Systems, *Behaviour and Information Technology,* pp.328-337.

MacKenzie, S. [1992], Fitts' law as a research and design tool in human-computer interaction*, Human- Computer Interaction*, Vol.7, pp. 91-139.

McGuffin, M. [2002], Fitts' law and expanding targets: an experimental study and applications to user interface design, M.Sc. Thesis, Department of Computer Science, University of Toronto.

McGuffin, M. and Balakrishnan, R. [2002], Acquisition of expanding targets, *In proceeding of the ACM Conference on Human Factors in Computing Systems (CHI'02)*, pp. 57-64.

Ren, X., and Moriya, S. [2000], Improving selection performance on pen-based system: A study of pen-based interaction for selection tasks, ACM Trans. *Computer-Human Interaction*, Vol.7, No.3. pp. 384-416.

Worden, A., Walker, N., Bharat, K., and Hudson, S. [1997], Making computers easier for older adults to use: area cursors and sticky icons, *In proceeding of the ACM Conference on Human Factors in Computing Systems (CHI'97)*, pp. 266-271.

Zhai, S., Buxton, W., and Milgram, P. [1994], The "Silk Cursor": Investigating transparency for 3D target acquisition, *In proceeding of the ACM Conference on Human Factors in Computing Systems (CHI'94)*, pp. 459-464.

Zhai, S., Conversy, S., Beaudouin-Lafon, M., and Guiard, Y. [2003], Human on-line response to target expansion, *In proceeding of the ACM Conference on Human Factors in Computing Systems (CHI'03),* pp. 177-184.